REMARKS

This is an Amendment after Allowance but before application of the issue fee payment to make minor grammatical and ideomatic changes to the specification as filed, without affecting the merits of this application. No new matter is involved. The merits of the claimed invention is not affected. Accordingly, entry of this Amendment under the provisions of 37 C.F.R 1.312 is warranted.

Applicant believes no fee is due with this response. However, if a fee is due, please charge our Deposit Account No. 18-0013, under Order No. SON-2647 from which the undersigned is authorized to draw.

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DESCRIPTION

REFLECTOR FOR EXPOSURE LIGHT AND ITS MANUFACTURE
METHOD, MASK, EXPOSURE APPARATUS AND SEMICONDUCTOR
5   DEVICE MANUFACTURE METHOD

TECHNICAL FIELD

          The present invention relates to a reflector for exposure light
having a function of reflecting exposure light, such as mask blanks of
10   exposure masks and reflection mirrors, the reflector being used when a
circuit pattern is transferred by exposure light to a subject to be exposed
such as a wafer in a lithograph process of manufacturing a semiconductor
device, and to a reflector manufacture method.   The present invention
also relates to a mask having a function of reflecting exposure light.   The
15   present invention also relates to an exposure apparatus constituted of
exposure light reflectors.   The present invention also relates to a
semiconductor device manufacture method using an exposure light mask.

BACKGROUND ART

20   Recent fine semiconductor devices require ~~to minimize~~the
minimization of a pattern width (line width), a pitch between patterns
and the like of a circuit pattern to be formed on a wafer and or a resist
pattern for forming the circuit pattern and the like.   This minimization
~~request~~ requirement can be dealt with by shortening the wavelength of
25   ultraviolet light to be used as exposure light to resist.   As
miniaturization of semiconductor devices progresses more, the
wavelength of ultraviolet light to be used as exposure light is shortened to,
for example, a wavelength of 365 nm for semiconductor devices under a
350 nm design rule, a wavelength of 248 nm for semiconductor devices
30   under a 250 nm and 180 nm design rule, and a wavelength of 193 nm for
semiconductor devices under a 130 nm and 100 nm design rule,

ultraviolet light having a wavelength of 157 nm being now in use.

It is ~~know~~ known that a resolution relative to a wavelength is generally expressed by the Rayleigh's equation $w = k1 \times (\lambda/NA)$ where w is a minimum width pattern to be resolved, NA is a numerical aperture

5　of a lens in a projection optical system, λ is a wavelength of exposure light and k1 is a process constant.　The process constant is determined mainly by the performance of resist, selection of ultra resolution techniques and the like.　It is known that k1 can be selected to be about 0.35 if optimum resist and ultra resolution techniques are used.　According to the ultra

10　resolution techniques, ± first order refraction light of light transmitted through a mask and refracted by a mask light shielding pattern is selectively used to obtain a pattern smaller than the wavelength.

It can be known from the Rayleigh's equation that the minimum pattern width capable of being dealt with if a wavelength of, for

15　example, 157 nm is used, is w = 61 nm by using a lens with NA = 0.9. Namely, if a pattern width narrower than 61 nm is to be obtained, it is necessary to use ultraviolet light having a wavelength shorter than 157 nm.

~~From~~ For this reason, studies have been made recently to

20　use light having a wavelength of 13.5 nm called extreme ultraviolet (EUV; Extreme Ultra Violet) light as ultraviolet light having a wavelength shorter than 157 nm.　Since there is light transmission material such as CaF_2 (calcium fluoride) and SiO_2 (silicon dioxide) for ultraviolet light having a wavelength of 157 nm or longer, it is possible to

25　form a mask and an optical system capable of transmitting the ultraviolet light.　However, for the extreme ultraviolet light having a wavelength of 13.5 nm, material capable of transmitting the extreme ultraviolet light at a desired thickness does not exist.　Therefore, if the extreme ultraviolet light having a wavelength of 13.5 nm is used, ~~not~~ a mask and an optical

30　system of a light transmission type cannot be used, but rather a mask and an optical system of a light reflection type is required ~~to be used~~.

2

If a mask and an optical system of the light reflection type are used, light reflected from a mask surface is required to be guided to a projection optical system without being interfered with by light incident upon the mask.   It is therefore essential that light incident upon the

5   mask is required to be oblique at an angle φ relative to the normal to the mask surface.   This angle is determined from the numerical aperture NA of a lens in a projection optical system, a mask multiplication m and a size σ of an illumination light source.   Specifically, in an exposure apparatus with NA = 0.3 and σ = 0.8, light is incident upon a mask,

10   having a solid angle of 3.44 ± 2.75 degrees.   If a mask having a reduction factor of 4 relative to a wafer is used and an exposure apparatus has NA = 0.25 and σ = 0.7, light is incident upon the mask, having a solid angle of 3.58 ± 2.51 degrees.

As a reflection type mask for use with oblique incidence light,

15   a mask blank is known which reflects extreme ultraviolet light and has an absorption film covering the mask blank with a predetermined pattern and absorbing extreme ultraviolet light and a buffer film interposed between the mask blank and absorption film.   The mask blank has the structure that an Si (silicon) layer and an Mo (molybdenum) layer are

20   alternately stacked, and the repetition number of stacks is generally 40 layers.   Since the absorption film for extreme ultraviolet light covers the mask blank with a predetermined pattern, incidence light is selectively reflected in accordance with a circuit pattern to be formed, a resist pattern or the like.   The buffer film is formed, as an etching stopper

25   when the absorption film is formed, or in order to avoid damages to be caused when defects are removed after the absorption mask is formed.

As described above, a conventional mask blank has generally 40 layers as the repetition number of stacks of the Si layer and Mo layer. A reflectance of Si is 0.9993 – 0.00182645i and a reflectance of Mo is

30   0.9211 – 0.00643543i, where i is an imaginary unit.   It is known that a proper ratio Γ of a Mo layer thickness to a total thickness of the Si layer

and Mo layer is Mo layer thickness / (Si layer thickness + Mo layer thickness) = 0.4. Therefore, in a conventional mask blank, if the wavelength λ of extreme ultraviolet light to be used for exposure is 13. 5 nm, the total thickness of the Si layer and Mo layer is $(\lambda/2)/(0.9993 \times 0.6 +$

5    $0.9211 \times 0.4) = 6.973$ nm, a thickness of the Si layer is $6.9730 \times 0.6 = 4.184$, and a thickness of an Mo layer is $6.9730 \times 0.4 = 2.789$ nm. Fig. 1 shows a reflectance of the mask blank having 40 layers of the stack of the Si layer and Mo layer described above. In the example shown in Fig. 1, the reflectance is at an incidence angle of 4.84 degrees. The incidence

10   angle is defined as an angle relative to the normal to the surface of the mask blank.

The alternately stacked <s>structure that the</s> Si layer and Mo layer structure <s>are alternately stacked</s> is used not only for a mask blank of the reflection type but also for a reflection mirror constituting a

15   reflection type optical system in quite a similar manner. Namely, the reflection mirror for extreme ultraviolet light has generally 40 layers as the repetition number of stacks of the Si layer and Mo layer, and the reflectance shown in Fig. 1 is obtained by properly setting the thicknesses of the Si layer and Mo layer when the wavelength of extreme ultraviolet

20   light is 13. 5 nm.

Extreme ultraviolet light generally propagates via a plurality of reflection surfaces from a light source of an exposure apparatus to resist coated on a wafer, for example, six mirror reflection surfaces of an illumination optical system, six mirror reflection surfaces

25   of a projection optical system and one reflection surface of a mask, thirteen surfaces in total. Extreme ultraviolet light emitted from the light source is attenuated upon reflection at a reflection surface. If this attenuation is large, sufficient energy cannot reach the resist coated on the wafer and there is a <s>fear</s> possibility that pattern formation and the

30   like cannot be performed properly.

If extreme ultraviolet light propagates via a plurality of

reflection surfaces, the energy reaching the resist coated on a wafer can be estimated from a reflectance at each of the plurality of reflection surfaces and a light source intensity. A reflectance R via a plurality of reflection planes is given by the following equation (1) if the light

5 propagates via thirteen reflection surfaces in total. R_{TE} is a reflectance of a TE wave per one reflection surface and R_{TM} is a reflectance of a TM wave per one reflection surface.

$$R = \{(R_{TE} + R_{TM})/2\}^{13} \qquad \ldots\ldots (1)$$

A reflectance R of thirteen surfaces in total was obtained by

10 using the equation (1) when the mask blank and reflection mirrors having the reflectance shown in Fig. 1 are used. The reflectance R is as shown in Fig. 4. It can be seen from the example shown in Fig. 4 that the center of the half width of a spectrum of the reflectance R is not coincident with 13.5 nm which is the center wavelength of exposure light

15 of extreme ultraviolet light. Namely, even if the center of FWHM (Full Width at Half Maximum) of a reflectance per one reflection surface is coincident with the center wavelength of exposure light (refer to Fig. 1), the center of FWHM of the reflectance R via thirteen reflection surfaces in total is not necessarily coincident with the center wavelength of

20 exposure light and the wavelength dependency may deviate from the center wavelength of exposure light. This results from <u>the fact</u> that the peak wavelength for the reflectance per one reflection surface is not coincident with 13.5 nm which is the center wavelength of exposure light of extreme ultraviolet light. As above, if the wavelength dependency

25 of the reflectance via a plurality of reflection surfaces deviates from the center wavelength of exposure light of extreme ultraviolet light, attenuation at the center wavelength of exposure light, i.e., attenuation of a light source intensity of the light source, becomes large. Therefore, ~~sufficient energy will not reach~~ at an exposure light wavelength suitable

30 for resist coated on a wafer, <u>sufficient energy will not reach the wafer</u> and the probability that pattern formation and the like cannot be performed

properly becomes very high.

It is therefore an object of the present invention to provide a reflector for exposure light which can retain a sufficient energy reaching a subject to be exposed, by making the wavelength dependency of a

5   reflectance via a plurality of reflection surfaces be coincident with the center wavelength of exposure light ~~of exposure light~~ such as extreme ultraviolet light.

In a lithography process for manufacturing a semiconductor device, a number (a variety) of exposure masks ~~is~~ are used in some cases.

10   Further, if there are a plurality of exposure apparatuses and manufacture is executed at a plurality of factories, a plurality of exposure masks are often used even for the same product and even in the same process.   In such cases, it is fairly conceivable that thicknesses of films and the like constituting each of a plurality of exposure masks have ~~a~~

15   ~~manufacture variation~~manufacturing variations.

The ~~manufacture variation~~manufacturing variations of this type, i.e., a thickness variation of films and the like constituting each exposure mask, causes a deviation of the center of FWHM of the reflectance relative to extreme ultraviolet light, which may result in a

20   reduction in arrival energy at an exposure light wavelength suitable for resist coated on a wafer.   It is therefore desired to remove the variation as much as possible.   However, for example, when the productivity of mask blanks is considered, it is not realistic to limit the film thickness and the like too severely.

25   It is therefore an object of the present invention to provide a reflector for exposure light, its manufacture method, a mask, an exposure apparatus and a semiconductor device manufacture method, which can retain a sufficient energy reaching a subject to be exposed, by making the wavelength dependency of a reflectance via a plurality of reflection

30   surfaces be coincident with the center wavelength of exposure light ~~of exposure light~~ such as extreme ultraviolet light.

6

Disclosure of the Invention

The present invention is a reflector for exposure light
devised in order to achieve the above-described objects.   The reflector for

5   exposure light is characterized in that it has a multi-layer film structure
~~that~~ wherein a plurality of layers are repetitively stacked in the same
order, that a periodical length of a repetitive stack unit of the multi-layer
film structure is set so that a center of FWHM of a reflectance via a
predetermined number of reflectors becomes coincident with a center

10   wavelength of exposure light to be reflected, and that the reflector is used
when the exposure light is exposed to a subject to be exposed in a
lithography process for manufacture of a semiconductor device.

In addition to the periodical length of the repetitive stack
unit of the multi-layer film structure, a film thickness ratio between a

15   plurality of layers constituting the repetitive stack unit may also be set so
that the center of FWHM of the reflectance via the predetermined
number of reflectors becomes coincident with the center wavelength of
exposure light to be reflected.

The present invention is a method of manufacturing a

20   reflector for exposure light devised in order to achieve the above-
described object.   Namely, the method is characterized in that a multi-
layer film structure made by repetitively stacking a plurality of layers in
the same order is formed by setting a periodical length of a repetitive
stack unit of the multi-layer film structure and a film thickness ratio

25   between a plurality of layers constituting the repetitive stack unit in such
a manner that a center of FWHM of a reflectance via a predetermined
number of reflectors becomes coincident with a center wavelength of
exposure light to be reflected.

The present invention is a mask devised in order to achieve

30   the above-described object and used when exposure light is exposed to a
subject to be exposed in a lithography process for manufacture of a

7

semiconductor device.   The mask is characterized by including a reflector portion having a multi-layer film structure made by repetitively stacking a plurality of layers in the same order and an absorption film portion covering the reflector portion with a predetermined pattern, wherein the

5   mask is structured so that there is a phase difference between reflection light of exposure light from the reflector portion and reflection light of the exposure light from the absorption film portion, and that in the reflection portion a periodical length of a repetitive stack unit of the multi-layer film structure and a film thickness ratio between the plurality of layers

10   constituting the repetitive stack unit are set so that a center of FWHM of a reflectance via a predetermined number of reflectors becomes coincident with a center wavelength of exposure light to be reflected.

       The present invention is an exposure apparatus devised in order to achieve the above-described object and used when exposure light

15   is exposed to a subject to be exposed in a lithography process for manufacture of a semiconductor device.   The exposure apparatus is characterized by including a predetermined number of reflectors for exposure light, the reflector having a multi-layer film structure made by repetitively stacking a plurality of layers in the same order, wherein in

20   the reflector for exposure light a periodical length of a repetitive stack unit of the multi-layer film structure and a film thickness ratio between the plurality of layers constituting the repetitive stack unit are set so that a center of FWHM of a reflectance via the predetermined number of reflectors becomes coincident with a center wavelength of exposure light

25   to be reflected.

       The present invention is a semiconductor device manufacture method devised in order to achieve the above-described object.   The semiconductor device manufacture method is characterized by including a reflector portion having a multi-layer film structure made

30   by repetitively stacking a plurality of layers in the same order and an absorption film portion covering the reflector portion with a

<div align="center">8</div>

predetermined pattern, wherein exposure light is exposed to a subject to

be exposed in a lithography process for manufacture of a semiconductor

device, by using a mask structured so that there is a phase difference

between reflection light of exposure light from the reflector portion and

5   reflection light of the exposure light from the absorption film portion, and

that in the reflection portion a periodical length of a repetitive stack unit

of the multi-layer film structure and a film thickness ratio of the plurality

of layers constituting the repetitive stack unit are set so that a center of

FWHM of a reflectance via a predetermined number of reflectors becomes

10   coincident with a center wavelength of exposure light to be reflected.

According to the above-described reflector for exposure light,

the periodical length of the repetitive stack unit of the multi-layer film

structure is set so that the center of FWHM of the reflectance via a

predetermined number of reflectors becomes coincident with the center

15   wavelength of exposure light to be reflected.   Therefore, the reflectance

of exposure light via the predetermined number of reflectors is coincident

with the center wavelength of the exposure light.   Accordingly,

attenuation of the exposure light intensity can be prevented from

becoming large even if the exposure light propagates via the

20   predetermined number of reflectors, and it is possible to retain sufficient

arrival energy when exposure to the subject to be exposed is executed.

Further, according to the above-described reflector for

exposure light, its manufacture method, mask, exposure apparatus and

semiconductor device manufacture method, the periodical length of the

25   repetitive stack unit of the multi-layer film structure and the film

thickness ratio among a plurality of layers constituting the repetitive

stack unit are set so that the center of FWHM of the reflectance via a

predetermined number of reflectors becomes coincident with the center

wavelength of exposure light to be reflected.   Namely, by setting also the

30   film thickness ratio between a plurality of layers, the center of FWHM of

the reflectance becomes coincident with the center wavelength of

9

exposure light even if the total film thickness of the multi-layer film structure is shifted.   Accordingly, an allowable variation width of the total film thickness of the multi-layer film structure can be broadened. Even in this case, attenuation of the exposure light intensity can be

5   prevented from becoming large, and it is possible to retain sufficient arrival energy when exposure to the subject to be exposed is executed.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is an illustrative diagram showing an example of

10   reflectances when a single reflector is used for extreme ultraviolet light, and more specifically a diagram showing reflectances by one reflector surface of a multi-layer film structure made by stacking 40 layers of Si 4.184 nm / Mo 2.789 nm at a periodical length 6.973 nm of a film thickness.

15   Fig. 2 is a cross sectional side view showing an example of the outline structure of a reflector for exposure light according to the present invention.

Fig. 3 is a perspective view showing an example of the outline structure of a mask according to the present invention.

20   Fig. 4 is an illustrative diagram showing an example of reflectances when extreme ultraviolet light propagates via a plurality of reflectors, and more specifically a diagram showing reflectances by thirteen reflector surfaces each constituted of a multi-layer film structure made by stacking 40 layers of Si 4.184 nm / Mo 2.789 nm at a periodical

25   length 6.973 nm of a film thickness.

Fig. 5 is an illustrative diagram showing an example of reflectances when extreme ultraviolet light propagates via a single reflector according to the present invention, and more specifically a diagram showing reflectances by a single reflector surface constituted of a

30   multi-layer film structure made by stacking 40 layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness.

Fig. 6 is an illustrative diagram showing an example of reflectances when extreme ultraviolet light propagates via a plurality of reflectors according to the present invention, and more specifically a diagram showing reflectances by thirteen reflector surfaces each

5   constituted of a multi-layer film structure made by stacking 40 layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness.

Fig. 7 is a flow chart illustrating an example of a manufacture procedure for a reflector to be used with extreme ultraviolet light according to the present invention.

10   Fig. 8 is an illustrative diagram showing an example of the results of relative energies reaching wafers when there is a film thickness variation of respective layers constituting a multi-layer film structure.

Fig. 9 is an illustrative diagram showing an example of reflectances by a single reflector when there is a variation of total film

15   thicknesses of multi-layer film structures, and more specifically a diagram showing reflectances R_{mask} of thinner and thicker cases of the total film thickness $d_{total} = 278$ nm of a multi-layer film structure made by stacking 40 layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness.

20   Fig. 10 is an illustrative diagram showing an example of reflectances by a plurality of reflectors when there is a variation of total film thicknesses of multi-layer film structures, and more specifically a diagram showing reflectances R_{total} by twelve multi-layer film mirrors each having a total thickness $d_{total} = 278$ nm and manufactured by

25   stacking 40 layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness and via one mask blank having the multi-layer film structure and a variation of total film thicknesses d_{total}.

Fig. 11 is an illustrative diagram showing an example of relative energies reaching wafers when there is a variation of total

30   thicknesses of multi-layer film structures, and more specifically a diagram showing relative energies $E_{relative}$ via the propagation route of

twelve multi-layer film mirrors each having a total thickness $d_{total} = 278$ nm and manufactured by stacking 40 layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness and one mask blank having the multi-layer film structure and a variation of the total film

5   thicknesses d_{total}.

Fig. 12 is an illustrative diagram showing an example of the relation between a periodical length of a film thickness and an optimum Γ value of a multi-layer film structure.

Fig. 13 is an illustrative diagram showing an example of

10   reflectances by a single reflector for extreme ultraviolet light having an optimum Γ value according to the present invention, and more specifically a diagram ~~showi~~ showing reflectances R_{mask} by one reflector surface of a multi-layer film structure having an optimum combination of a total film thickness d_{total} and a Γ value and made by stacking 40 layers of Si 4.17

15   nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness.

Fig. 14 is an illustrative diagram showing an example of reflectances by a plurality of reflectors for extreme ultraviolet light having an optimum Γ value according to the present invention, and more specifically a diagram showing reflectances R_{total} by twelve multi-layer

20   film mirrors each having a total thickness $d_{total} = 278$ nm and manufactured by stacking 40 layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness and by one mask blank having an optimum Γ value.

Fig. 15 is an illustrative diagram showing an example of

25   relative energies reaching wafers via a plurality of reflectors for extreme ultraviolet light having an optimum Γ value according to the present invention, and more specifically a diagram showing relative energies $E_{relative}$ via the propagation route of twelve multi-layer film mirrors each having a total thickness $d_{total} = 278$ nm and manufactured by stacking 40

30   layers of Si 4.17 nm / Mo 2.78 nm at a periodical length 6.95 nm of a film thickness and one mask blank having an optimum Γ value.

Fig. 16 is an illustrative diagram showing an example of the results obtained by plotting allowable variation values of a total film thickness as a function of a relative energy, for both the cases wherein a Γ value is optimized and not optimized.

5   Fig. 17 is an illustrative diagram showing an example of TE wave phase difference distributions of a half tone phase shift mask at respective wavelengths, relative to a variation of total film thicknesses when a Γ value is not optimized.

Fig. 18 is an illustrative diagram showing an example of TM

10 wave phase difference distributions of a half tone phase shift mask at respective wavelengths, relative to a variation of total film thicknesses when a Γ value is not optimized.

Fig. 19 is an illustrative diagram showing an example of TE wave phase difference distributions of a half tone phase shift mask at

15 respective wavelengths, relative to a variation of total film thicknesses when a Γ value is optimized.

Fig. 20 is an illustrative diagram showing an example of TM wave phase difference distributions of a half tone phase shift mask at respective wavelengths, relative to a variation of total film thicknesses

20 when a Γ value is optimized.

Fig. 21 is an illustrative diagram showing an example of reflectance ratio distributions of a half tone phase shift mask at respective wavelengths, relative to a variation of total film thicknesses when a Γ value is not optimized.

25   Fig. 22 is an illustrative diagram showing an example of reflectance ratio distributions of a half tone phase shift mask at respective wavelengths, relative to a variation of total film thicknesses when a Γ value is optimized.

Fig. 23 is a schematic diagram showing an example of the

30 outline structure of an exposure apparatus.

Best Mode for Carrying Out the Invention

With reference to the drawings, description will be made on a reflector for extreme ultraviolet light and its manufacture method, a phase shift mask and an exposure apparatus according to the invention.

5   It is obvious that the present invention is not limited to preferred embodiments to be described below.

First, an example of an exposure apparatus will be described. The exposure apparatus described herein is used for exposing a subject (resist on a wafer) to extreme ultraviolet light in a manufacture process

10   for semiconductor devices, particularly in a lithography process of transferring a circuit pattern of a semiconductor device from an exposure mask to a wafer.   More ~~in detail~~specifically, the route from a light source for irradiating extreme ultraviolet light having a center wavelength of 13.5 nm to resist on a wafer which is a subject to be exposed, is structured

15   so that extreme ultraviolet light propagates via thirteen reflection surfaces in total, twelve mirror reflection surfaces of an optical system and one reflection surface of an exposure mask.

Next, description will be made ~~on~~ of a reflector for extreme ultraviolet light to be used by this exposure apparatus, i.e., a reflector for

20   extreme ultraviolet light according to the present invention.   The reflector for extreme ultraviolet light described herein is used as a reflection mirror constituting a mirror reflection surface of an optical system or a mask blank constituting a reflection surface of an exposure mask.   More ~~in detail~~specifically, as shown in Fig. 2, the reflector has a

25   multi-layer film structure made by repetitively stacking 40 layers each constituted of an Si layer 2 and an Mo layer 3 in the same order of Mo/Si/Mo/Si,..., Mo/Si from a low expansion glass 1 of, for example, SiO_2 (silicon dioxide) or the like toward the reflector surface (front surface). The reflector 4 having the multi-layer film structure of this type may be

30   formed by ion beam sputtering.   More specifically, the Si layer 2 and Mo layer 3 are formed at predetermined film forming speeds by using, for

14

example, an ion beam sputtering system.

In order to configure a reflection type exposure mask by using the reflector 4, as shown in Fig. 3 an absorption film 6 made of extreme ultraviolet light absorbing material such as TaN (tantalum

5 nitride) is formed on the reflector 4, with a buffer film 5 made of Ru (ruthenium) or the like being interposed therebetween. Namely, a light reflection surface side of the reflector 4 is covered with the absorption film 6 having a predetermined pattern so that incidence light can be selectively reflected in correspondence with a circuit pattern, resist

10 pattern or the like to be formed. If a reflection mirror is to be configured, the light reflection surface of the reflector is used as it is to reflect incidence light. For example, as the optical conditions, a center wavelength (exposure wavelength) of extreme ultraviolet light as incidence light is set to 13.5 nm, and as the exposure conditions, NA =

15 0.25 and $\sigma = 0.70$.

As already described, since the reflector having the multi-layer film structure of this type has an Si reflectance of $0.9993 - 0.00182645i$, an Mo reflectance of $0.9211 - 0.00643543i$ and an extreme ultraviolet light wavelength λ of 13.5 nm, generally a ratio Γ of a

20 thickness of the Mo layer to a total thickness of the Si layer and Mo layer is set to 0.4, a total thickness of the Si layer and Mo layer is set to $(\lambda/2)/(0.9993 \times 0.6 + 0.9211 \times 0.4) = 6.973$ nm, a thickness of the Si layer is set to $6.9730 \times 0.6 = 4.184$ nm and a thickness of the Mo layer is set to $6.9730 \times 0.4 = 2.789$ nm. However, with the reflector having the multi-

25 layer film structure constructed as above, as shown in Fig. 1, although the center of FWHM of the reflectance by a single reflector is coincident with the center wavelength of exposure light, the peak wavelength is shifted from the center wavelength of exposure light. Therefore, as shown in Fig. 4, the wavelength dependency of the reflectance R via the

30 propagation route of thirteen reflection surfaces in total may shift from the center wavelength of exposure light because the center of FWHM is

15

not always coincident with the center wavelength of exposure light.

The reflector 4 having the multi-layer film structure described in this preferred embodiment is designed to have a periodical length of a film thickness of a repetitive stack unit of the Si layer 2 and

5   Mo layer 3, different from a conventional design, in order to make the reflectance become coincident with the center wavelength of exposure light so that sufficient energy reaching resist can be retained even if the propagation route via thirteen reflection surfaces in total is used. Namely, with the reflector 4 described in the preferred embodiment, the

10   periodical length of the repetitive stack unit of the multi-layer film structure is set so that the center of FWHM of the reflectance via the thirteen reflection surfaces in total becomes coincident with the center wavelength of extreme ultraviolet light.

More specifically, a shift is considered between the peak

15   wavelength of the reflectance by a single reflector and the center wavelength of exposure light.   A correction corresponding to this shift amount is added to the value of the wavelength λ of extreme ultraviolet light and the total thickness of the Si layer 2 and Mo layer 3 is identified by an equation of $(\lambda/2)/(0.9997 \times 0.6 + 0.9221 \times 0.4)$ while the value of the

20   film thickness ratio Γ is maintained at 0.4.   In this manner, the reflector 4 described in this embodiment has the a structure such that the total thickness of the Si layer 2 and Mo layer 3, i.e., a periodical length of the repetitive stack unit, is 6.95 nm.   In this case, since $\Gamma = 0.4$, a film thickness of one Si layer 2 is 4.17 nm and a film thickness of one Mo layer

25   3 is 2.78 nm.

The reflector 4 structured as above has a reflectance spectrum by a single reflector wherein as shown in Fig. 5 the center of FWHM is not coincident width with the center wavelength of exposure light.   However, for the reflectance R via thirteen reflection surfaces in

30   total, as shown in Fig. 6 the center of FWHM is coincident with the center wavelength of exposure light.   This may be ascribed to the fact that since

16

the periodical length of a film thickness of the repetitive stack unit of the multi-layer film structure, i.e., the optical periodical length, is different from a conventional length, the wavelengths strengthening through interference by the multi-layer film structure are also different so that

5   the peak wavelength of the reflectance shifts.

Description will be made ~~on~~ of a ~~manufacture~~ manufacturing procedure for the reflector 4 having this structure.   Fig. 7 is a flow chart illustrating an example of a reflector ~~manufacture~~ manufacturing procedure.   As illustrated in this drawing, when the reflector 4 is

10   manufactured, first a reflectance spectrum is obtained at the route corresponding to the number of reflectors 4 mounted on the exposure apparatus, particularly, thirteen reflection surfaces in total (Step 101, hereinafter Step is abbreviated to "S").   The reflectance spectrum may be actually measured by forming a sample of the reflector or may be

15   obtained by utilizing simulation techniques.   After the reflectance spectrum is obtained, it is judged whether the center of FWHM of the reflectance spectrum is coincident with the center wavelength of exposure light of extreme ultraviolet light (S102).   If this judgement result indicates that both are not coincident, the periodical length of a film

20   thickness of the Si layer 2 and Mo layer 3 of the multi-layer film structure is changed so as to make both become coincident (setting is performed again), and thereafter the reflectance spectrum is again obtained at the route of thirteen reflection surfaces in total (S101).   These processes are repeated until both become coincident.   It can be considered that the film

25   thicknesses of the Si layer 2 and Mo layer 3 of the multi-layer film structure are set to have desired values by properly adjusting the film forming speeds, for example, of sputtering.

If the exposure apparatus, particularly an optical system formed by reflection mirrors, is structured by using the reflectors 4

30   formed in the above-described manner (e.g., reflector having a periodical length of a film thickness of 6.95 nm and Γ of 0.4), the reflectance R

17

becomes coincident with the center wavelength of exposure light even ~~at~~ as the route ~~that~~ of the extreme ultraviolet light propagates via thirteen reflection surfaces in total between the light source for extreme ultraviolet light and the resist on a wafer. It is therefore possible to

5 suppress a large attenuation of the intensity of extreme ultraviolet light and retain ~~a~~ sufficient energy for resist exposure.

Of the reflector 4 used by the exposure apparatus, a mask blank constituting an exposure mask among others is frequently changed with a circuit pattern to be transferred. Therefore, an individual

10 difference is inevitable, namely, a film thickness variation of multi-layer film structures of mask blanks is inevitable. The film thickness variation of multi-layer film structures is mainly classified into two variations, variations of respective thicknesses d_{Si} of Si layers 2 and respective thicknesses d_{Mo} of Mo layers 3 and a variation of total film

15 thicknesses d_{total} after 40 layers are stacked. This relation is represented by the following equation (2):

$$d_{total} = \sum_{j}^{40} djSi + \sum_{j}^{40} djMo \qquad \ldots\ldots (2)$$

wherein the variations of respective thicknesses d_{Si} of Si layers 2 and respective thicknesses d_{Mo} of Mo layers 3 do not influence greatly the

20 intensity reduction by reflection of extreme ultraviolet light if the variation of total film thicknesses d_{total} is restricted in a desired range. This can be confirmed by calculating the reflectance R_{total}, for example, via the route of thirteen reflection surfaces of the exposure apparatus including twelve reflection mirrors structured to have a periodical length

25 of a film thickness of 6.95 nm and $\Gamma = 0.4$ and one mask blank having a film thickness variation, by using the following equation (3) and a reflectance R_{12} via twelve reflection mirrors and a reflectance R_{mask} of the mask blank having a film thickness variation.

$$R_{total} = R_{12} \times R_{mask} \qquad \ldots\ldots (3)$$

30 More specifically, the mask blanks having variations of d_{Si}

18

and d_{Mo} are used, and the energies reaching resist on a wafer at standard

deviations $3\sigma = 0.5$ nm and $3\sigma = 1.0$ nm are compared with the energy at

$3\sigma = 0.0$ nm.   More ~~in detail~~specifically, the energy $E_{(3\sigma = 0.5)} = \int R_{total}\, d\lambda$ at

$3\sigma = 0.5$ nm and the energy $E_{(3\sigma = 1.0)} = \int R_{total}\, d\lambda$ at $3\sigma = 1.0$ nm are

5   obtained, and these energies are compared with the energy $E_{(3\sigma = 0)} = \int R_{total}$

$d\lambda$ at $3\sigma = 0.0$ nm.   These comparisons are performed by using the

following equations (4) and (5):

$$E_{relative} = E_{(3\sigma = 0.5)}/E_{(3\sigma = 0)} \qquad \ldots (4)$$

$$E_{relative} = E_{(3\sigma = 1.0)}/E_{(3\sigma = 0)} \qquad \ldots (5)$$

10   The comparison results of reaching energies at three types of

variations (variations A to C) obtained by using the equations (4) and (5)

are shown in Fig. 8.   In this case, if $E_{relative} \geq 0.95$ is used as the

judgement criterion based on the rule of thumb, as apparent from the

example shown in the drawing, the energy reaching degree does not pose

15   any problem at $3\sigma = 0.5$ nm, and ~~any~~ no problem occurs even at $3\sigma = 1.0$

nm for the two types of variations (variations A and B).   With respect to

these results, in the actual mask blank manufacture process, it is possible

to control the variation width narrower than that at $3\sigma = 0.5$.   If these

results are considered synthetically, it can be said that these variations

20   do not pose any problem even if there are variations of the film thickness

d_{Si} of Si layer 2 and the film thicknesses d_{Mo} of Mo layers 3.

          ~~As different from~~Unlike the variations of the film

thicknesses d_{Si} and d_{Mo} of the layers, the variation of the total film

thicknesses d_{total} greatly influences the intensity reduction of extreme

25   ultraviolet light by reflection.   This can be ascribed to <u>the fact</u> that, for

example, in the case of a multi-layer film structure having $\Gamma = 0.4$, even if

the center of FWHM of the reflectance spectrum is made coincident with

the center wavelength of exposure light of extreme ultraviolet light as

described previously, the center of FWHM shifts to the shorter

30   wavelength side from the center wavelength of exposure light if the total

film thicknesses d_{total} of the multi-layer film structure have a variation

and become thinner than a desired value, whereas the center of FWHM shifts to the longer wavelength side from the center wavelength of exposure light if the total film thickness becomes thicker than the desired value. Fig. 9 shows reflectances R_{mask} at variations from -3 nm to $+3$

5   nm of the total film thicknesses d_{total} of multi-layer film structures wherein, for example, Γ is 0.4, the film thickness of the Si layer 2 is 4.17 nm, the film thickness of the Mo layer 3 is 2.78 nm and the periodical length of the repetitive stack unit is 6. 95 nm. It can be seen from the example shown in the drawing that the center of FWHM of the

10   reflectance R_{mask} shifts to the shorter or longer wavelength side of the center wavelength of exposure light in accordance with the variation of the total film thicknesses d_{total}.

As different fromUnlike the variations of the film thicknesses d_{Si} and d_{Mo} of the layers, the variation of the total film

15   thicknesses d_{total} is required that a variation width thereof ismust be restricted in to be within a predetermined constant allowable range.

A variation width of the total film thickness d_{total} can be obtained as in the following for multi-layer film structures having, for example, Γ of 0.4. First, basing based upon the results shown in Fig. 9,

20   the reflectances R_{total} via thirteen surfaces in total relative to the variations of the total film thicknesses d_{total} are obtained. The results are shown in Fig. 10. The energies reaching resist on a wafer are obtained from the results shown in Fig. 10 and compared each other. More specifically, for example, the total film thickness d_{total} is changed

25   from -3 nm to $+3$ nm and the reaching energies $E(\Delta d_{total} = -3) = \int R_{total} \, d\lambda$, $E(\Delta d_{total} = -2) = \int R_{total} \, d\lambda$, $E(\Delta d_{total} = -1) = \int R_{total} \, d\lambda$, $E(\Delta d_{total} = +1) = \int R_{total} \, d\lambda$, $E(\Delta d_{total} = +2) = \int R_{total} \, d\lambda$, $E(\Delta d_{total} = +3) = \int R_{total} \, d\lambda$ are obtained and compared with the reaching energy $E(\Delta d_{total} = 0) = \int R_{total} \, d\lambda$ with no variation.

30   Namely, the relative energies reaching the wafer at the variations of the d_{total} are obtained, including $E_{relative} = E(\Delta d_{total} =$

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$-3)/E(\Delta d_{total} = 0)$, $E_{relative} = E(\Delta d_{total} = -2)/E(\Delta d_{total} = 0)$, $E(\Delta d_{total} = -1)/E(\Delta d_{total} = 0)$, $E_{relative} = E(\Delta d_{total} = 0)/E(\Delta d_{total} = 0)$, $E_{relative} = E(\Delta d_{total} = +1)/E(\Delta d_{total} = 0)$, $E_{relative} = E(\Delta d_{total} = +2)/E(\Delta d_{total} = 0)$, and $E(\Delta d_{total} = +3)/E(\Delta d_{total} = 0)$. The comparison results of the energies $E_{relative}$ obtained

5   in this manner are shown in Fig. 11.

The allowable range of the variation of d_{total} can be obtained from the comparison results of the energies $E_{relative}$ relative to Δd_{total}. Namely, if $E_{relative} \geq 0.95$ based on the rule of thumb is used as the judgement criterion, it can be seen also from the results shown in Fig. 11

10   that the allowable variation of d_{total} is in the range from -2.195 nm to $+2.755$ nm and in the range width of 4. 95 nm. In other words, for multi-layer film structures having Γ of 0.4, a variation of 1.78% is allowable for the reference value $d_{total} = 278$ nm.

However, if the productivity of, for example, a mask blank, is

15   considered, it is needless to say that the allowable variation of d_{total} is desired to have a broad width. In this context, multi-layer film structures are not configured to make the variation of the total film thicknesses d_{total} ~~falls~~ fall in the allowable range while Γ is fixed to a constant value, but the allowable range of the variation of d_{total} can be

20   broadened by selecting an optimum Γ value together with the above-described periodical length of the film thickness of the multi-layer film structure.

Detailed description will be made on selecting an optimum Γ value. For example, the relation between the periodical length of the

25   film thickness and an optimum Γ of a multi-layer film structure is ~~given, for example, as~~ shown in Fig. 12. More specifically, if the periodical length of a film thickness is 6.88 nm, $\Gamma = 0.25$ (in this case, the total film thickness $d_{total} = 275.2$ nm, the film thickness of one Si layer = 5.1600 nm and the film thickness of one Mo layer = 1.7200 nm); if the periodical

30   length of a film thickness is 6.90 nm, $\Gamma = 0.30$ (in this case, the total film thickness $d_{total} = 276.0$ nm, the film thickness of one Si layer = 4.8300 and

the film thickness of one Mo layer = 2.0700 nm), Γ = 0.25 (in this case, the total film thickness d_{total} = 275.2 nm, the film thickness of one Si layer = 5.1600 nm and the film thickness of one Mo layer = 1.7200 nm); if the periodical length of a film thickness is 6.90 nm, Γ = 0.30 (in this case, the

5   total film thickness d_{total} = 276.0 nm, the film thickness of one Si layer = 4.8300 nm and the film thickness of one Mo layer = 2.0700 nm); if the periodical length of a film thickness is 6.92 nm[[;]], Γ = 0.35 (in this case, the total film thickness d_{total} =276.8 nm, the film thickness of one Si layer = 4.4980 nm and the film thickness of one Mo layer = 2.4220 nm); if the

10   periodical length of a film thickness is 6.95 nm, Γ = 0.40 (in this case, the total film thickness d_{total} = 278.0 nm, the film thickness of one Si layer = 4.1700 nm and the film thickness of one Mo layer = 2.7800 nm); if the periodical length of a film thickness is 6.98 nm, Γ = 0.45 (in this case, the total film thickness d_{total} = 279.2 nm, the film thickness of one Si layer =

15   3.8390 nm and the film thickness of one Mo layer = 3.1410 nm); if the periodical length of a film thickness is 7.01 nm, Γ = 0.50 (in this case, the total film thickness d_{total} = 280.4 nm, the film thickness of one Si layer = 3.5050 nm and the film thickness of one Mo layer = 3.5050 nm); if the periodical length of a film thickness is 7.03 nm, Γ = 0.55 (in this case, the

20   total film thickness d_{total} = 281.2 nm, the film thickness of one Si layer = 3.1635 nm and the film thickness of one Mo layer = 3.8665 nm); and if the periodical length of a film thickness is 7.05 nm, Γ = 0.60 (in this case, the total film thickness d_{total} = 282.0 nm, the film thickness of one Si layer = 2.8200 nm and the film thickness of one Mo layer = 4.2300 nm).

25   Fig. 13 shows reflectances by a single multi-layer film structure, i.e., by a single reflection surface when optimum Γ values are selected.   It can be understood from the example shown in the drawing that even if the total thickness d_{total} shifts, the wavelength giving the peak intensity will not be changed by optimizing a combination of the

30   periodical length of a film thickness and Γ value.

             Fig. 14 shows reflectances R_{total} via thirteen surfaces in total

22

when optimum Γ values are selected.   It can be understood from the example shown in the drawing that the half value center of the reflectance is always coincident with the center wavelength of exposure light at 13.5 nm.

5   The energies reaching resist on a wafer are obtained from the results shown in Fig. 14 and they are compared with each other. Specifically, the reaching energies when the optimum Γ values are selected are obtained, including $E(\Gamma = 0.25) = \int R_{total} \, d\lambda$, $E(\Gamma = 0.30) = \int R_{total} \, d\lambda$, $E(\Gamma = 0.35) = \int R_{total} \, d\lambda$, $E(\Gamma = 0.40) = \int R_{total} \, d\lambda$, $E(\Gamma = 0.45) = \int R_{total} \, d\lambda$,

10        $E(\Gamma = 0.50) = \int R_{total} \, d\lambda$, $E(\Gamma = 0.55) = \int R_{total} \, d\lambda$, and $E(\Gamma = 0.60) = \int R_{total} \, d\lambda$, and compared with $E(\Gamma = 0.40) = \int R_{total} \, d\lambda$ used as a reference.

          Namely, the relative energies reaching the wafer at the variations of d_{total} are obtained, including $E_{relative} = E(\Gamma = 0.25)/E(\Gamma = 0.40)$, $E(\Gamma = 0.30)/E(\Gamma = 0.40)$, $E(\Gamma = 0.35)/E(\Gamma = 0.40)$, $E(\Gamma = 0.40)/E(\Gamma = 0.40)$,

15        $E(\Gamma = 0.45)/E(\Gamma = 0.40)$, $E(\Gamma = 0.50)/E(\Gamma = 0.40)$, $E(\Gamma = 0.55)/E(\Gamma = 0.40)$, and $E(\Gamma = 0.60)/E(\Gamma = 0.40)$.   The comparison results of $E_{relative}$ obtained in this manner are shown in Fig. 15.

          The allowable range of the variation of d_{total} can be obtained from the comparison results of $E_{relative}$ obtained in this manner.   Namely,

20   if $E_{relative} \geq 0.95$ based on the rule of thumb is used as the judgement criterion, it can be seen also from the results shown in Fig. 15 that the allowable variation of d_{total} is in the range from -2.220 nm to $+3.585$ nm and in the range width of 5.805 nm.   This means that a variation of 2.09 % is allowable for the reference value $d_{total} = 278$ nm.

25   Namely, if the multi-layer film structure is configured not by fixing Γ to a constant value but by selecting an optimum Γ value together with the periodical length of a film thickness, the allowable variation value of the total thickness d_{total} of the multi-layer film structure increases.   Fig. 16 shows the results obtained by plotting the allowable

30   variation values of the total film thickness d_{total} as a function of $E_{relative}$ in both cases when the Γ value is optimized and not optimized.   It can be

23

seen also from the example shown in the drawing that if the Γ value is optimized, the allowable variation value increases more than if the Γ value is not optimized, and that in the same variation range, a lager energy can be obtained than if the Γ value is not optimized.

5   It can be considered from this that of the reflectors 4 used by the exposure apparatus, the mask blank constituting the exposure mask among others is manufactured by selecting the optimum Γ value together with the periodical length of a film thickness.   Namely, in the mask blank manufacture process, if d_{total} is shifted from the d_{total} reference

10   value of 278 nm at $\Gamma = 0.40$, the film forming conditions are selected from Fig. 12 so as to obtain an optimum relation between the Γ value and d_{total}.

         More specifically, as shown in Fig. 7, after the exposure apparatus is configured having twelve reflection surfaces of the reflection mirrors having the periodical length of a film thickness set in the manner

15   already described (S103), a mask blank used for the exposure apparatus is manufactured (S104).   Before this manufacture, first the total film thickness d_{total} of the multi-layer film structure is obtained (S105).   The total film thickness d_{total} may be actually measured by forming a sample of the mask blank or may be obtained by utilizing simulation techniques.

20   It is assumed that the multi-layer film structure has Γ of 0.40.

         After the total film thickness d_{total} is obtained, the periodical length of the film thickness at the total film thickness d_{total} is obtained (S106) to judge whether the periodical length of the film thickness is shifted from a predetermined reference value, e.g., the reference value of

25   278 nm at $\Gamma = 0.40$.   If it is shifted from the reference value, the Γ value is optimized to change the periodical length of the film thickness and Γ value (to perform setting again) and thereafter the above-described Steps are repeated.

         Namely, in manufacturing a mask blank, in addition to the

30   periodical length of the repetitive stack unit of the multi-layer film structure, the Γ value, which is the film thickness ratio between the Si

24

layer and Mo layer constituting the repetitive stack unit, is also set in such a manner that the center of FWHM of the reflectance R_{total} via thirteen surfaces in total becomes coincident with the center wavelength of extreme ultraviolet light (refer to Fig. 14) to configure the multi-layer

5   film structure.

As the exposure mask is constituted of the mask blank obtained in this manner, the allowable variation width of the total film thickness d_{total} can be broadened.   It can therefore be expected that the productivity of mask blanks (exposure masks) is improved so that it is

10   possible to realize ~~the~~ an improvement ~~on a~~ in ~~manufacture~~ manufacturing efficiency of semiconductor devices, the reduction of ~~a~~ ~~manufacture cost~~ manufacturing costs and the like.   Furthermore, also in this case, since it is possible to suppress the intensity of extreme ultraviolet light from being attenuated considerably, a sufficient reaching

15   energy for exposure to resist can be retained and it is possible to avoid beforehand ~~the~~ a degradation in manufacture quality and the like of semiconductor devices ~~from being degraded~~.

In this description, although optimization of the Γ value is used by way of example when a mask blank is manufactured, it is obvious

20   that the Γ value is optimized when a reflection mirror is manufactured. Namely, the optimization of the Γ value described in the embodiment is applicable to all types of reflectors for extreme ultraviolet light. Therefore, remarkable effects can be obtained relative to the film thickness variation of, for example, a half tone phase shift mask blank, by

25   optimizing the Γ value.

Description will be made ~~on~~ of application of the optimization of a Γ value of a half tone phase shift mask blank.   As an example of a half tone phase shift, a mask blank of a multi-layer film structure for reflecting extreme ultraviolet light is used on which a TaN

30   film of extreme ultraviolet light absorbing material is formed with a Ru film being interposed therebetween.   This half tone phase shift mask

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provides a phase shift mask function by setting a phase difference of 180

degrees between light reflected from the reflection surface of the mask

blank and light reflected from the surface of the TaN film.   For example,

the film thicknesses giving a phase difference of 180 degrees are 13 nm

5   for the R film and 30 nm for the TaN film.

Figs. 17 and 18 show the wavelength dependency of a phase

difference when the Γ value is not optimized relative to the variation of

the total film thicknesses d_{total} of mask blanks of the above-described half

tone phase shift mask.   Fig. 17 is a diagram showing the phase

10   difference distribution of TE waves, and Fig. 18 is a diagram showing the

phase difference distribution of TM waves.   It can be seen from the

examples shown in these drawings that the phase difference range is

from 167 degrees to 184 degrees if the Γ value is not optimized.

In contrast, Figs. 19 and 20 show the wavelength

15   dependency of a phase difference when the Γ value is optimized relative

to the variation of the total film thicknesses d_{total} of mask blanks of the

half tone phase shift mask.   Fig. 19 is a diagram showing the phase

difference distribution of TE waves, and Fig. 20 is a diagram showing the

phase difference distribution of TM waves.   It can be seen from the

20   examples shown in these drawings that the phase difference distribution

width is improved from 167 degrees to 183 degrees if the Γ value is

optimized.   Namely, by optimizing the Γ value, the phase difference

distribution width is improved by about 6 %.

Fig. 21 shows a ratio $T_{ratio} = T_{(Ru + TaN)}/T_{blank}$ of a reflectance

25    $T_{(R + TaN)}$ of the R film and TaN film when the Γ value is not optimized

relative to the variation of the total film thicknesses d_{total} of mask blanks

to a reflectance T_{blank} of mask blanks.   This ratio T_{ratio} is desired to have

a small distribution, similar to the phase difference distribution.   In

contrast, Fig. 22 shows the ratio T_{ratio} when the Γ value is optimized.

30   From the comparison of these examples shown in the drawings, it can be

seen that the wavelength dependency of the reflectance ratio becomes

small by optimizing the Γ value.

Namely, as the optimization of the Γ value is applied to the blank of the half tone phase shift mask, a phase shift mask can be realized wherein not only the variation width of the total film thickness

5   d_{total} is broadened, but also the phase difference distribution and reflectance ratio distribution are small.

In the above description, although the exposure apparatus constituted of thirteen reflection surfaces in total is used by way of example, the invention is also applicable to exposure of different types.

10   Fig. 23 is a diagram showing an example of the outline structure of another exposure apparatus.   In an exposure apparatus 10 in the example shown in the drawing, exposure light output from a light source 11 of extreme ultraviolet light is separated by a beam splitter 12, narrowed to a proper angle by a prism unit 13 and passes through a fly

15   eye lens 14 to form modified illumination or annular illumination to be described later.   This light is reflected by (or transmitted through) a mask pattern of a reticle 16 via an illumination lens system 15, converged by a focussing lens system 17, and becomes obliquely incident illumination for resist coated on a wafer 18.   Instead of using the beam

20   splitter 12 and prism unit 13, the modified illumination or half tone annular illumination may be formed by using a filter which transmits an amount of light equal to or larger than some degree through a light source center and its nearby area.   Further, if a mercury lamp is used as the light source 3 shown in Fig. 2, an exposure apparatus with an i-line

25   stepper can be realized.   The invention is not limited to this, but other types of exposure apparatuses may also be used such as a g-line stepper, a KrF excimer laser stepper, and an ArF excimer laser stepper.

The exposure beam is not limited only to extreme ultraviolet light but other beams may be used such as ultraviolet light, an electron

30   beam, an X-ray, a radial ray, a charged particle ray, and a light ray, with which the present invention can be properly reduced in practice.

27

For example, one ~~of~~ electron beam exposure ~~techniques~~ technique is low energy electron proximity projection lithography (LEEPL).   LEEPL uses a stencil mask made of a membrane having a thickness of several hundreds nm and formed with holes corresponding to

5   a device pattern.   A mask is disposed just above a wafer at a distance of several tens μm between the mask and wafer.   The pattern area of the mask is scanned with an electron beam at several tens keV to transfer the pattern to the wafer (T. Utsumi, Journal of Vacuum Science and Technology B17, 2897 (1999)).   In this manner, an electron beam emitted

10   from a low acceleration electron gun passes through an aperture, is changed to a parallel beam by a condenser lens, and passes through a deflector to be irradiated on a wafer via the mask.   Also in this case, by using a mask described in the present invention, it becomes possible to properly deal with a micro fine pattern width and pattern pitch of a

15   transfer image so that the present invention can contribute to the improvement on the performance of semiconductor devices.

    There is a method of supporting a small segment membrane by a beam structure (grid structure).   This is used by a mask of SCALPEL (scattering with angular limitation in projection electron-beam

20   lithography), PREVAIL (projection exposure with variable axis immersion lenses) and an EB stepper (for example, L. R. Harriott, Journal of Vacuum Science ~~nd~~ and Technology B15, 2130 (1997); H. C. Pfeiffer, Japanese Journal of Applied Physics 34, 6658 (1995)).   With SCALPEL, an electron beam emitted from a low acceleration electron gun

25   ~~passed~~ passes through an aperture, is changed to a parallel beam by a condenser lens, and passes through a deflector to be irradiated to a wafer via a mask.   With PREVAIL, a condenser lens, a reticle, a first projection lens, a crossover aperture, a second projection lens, a sample, and a lens under the sample are sequentially arranged from an electron source side

30   to transfer a reticle pattern to the sample.   Also in these cases, by using a mask described in the present invention, it becomes possible to properly

deal with a micro fine pattern width and pattern pitch of a transfer image so that the present invention can contribute to the improvement ~~on~~ of the performance of semiconductor devices.

Even if not only extreme ultraviolet light, but also

5   ultraviolet light, an electron beam, an X-ray, a radial ray, a charged particle ray or a light ray is used as the exposure beam, a line width variation and a pattern position misalignment after exposure to a wafer can be minimized by applying the present invention. Therefore, it becomes possible to properly deal with a micro fine pattern width and

10   pattern pitch of a transfer image so that the present invention can contribute to the improvement ~~on~~ of the performance of semiconductor devices.

Industrial Applicability

15   As described above, according to a reflector for extreme ultraviolet light, its manufacture method, a phase shift mask, an exposure apparatus and a semiconductor manufacture method of the present invention, the wavelength dependency of a reflectance via a plurality of reflection surfaces can be made coincident with the center

20   wavelength of exposure light of extreme ultraviolet light.   Accordingly, it is possible to retain a sufficient reaching energy for exposure of a subject to be exposed.   Further, if an optimum Γ value is selected, the allowable variation width of a film thickness of the reflector can be broadened so that a sufficient energy reaching an exposure subject can be retained

25   without degrading the productivity and the like of reflectors.